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Laser exposure of high-pressure arc electrodes

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The influence of a laser exposure of an arc electrode working alternatively as anode or as cathode on the discharge voltage and on the electrode temperatures is studied.

1. Introduction

Over the next years, electrodes will be the essential means for feeding electrical energy into an arc discharge lamp. The voltages which arise in the immediate neighborhood of the electrodes (electrode sheath voltage – ESV) represent a non-negligible part of the total arc voltage. They will, however, not contribute to the light output but are rather necessary to maintain the unhindered flow of charge carriers from the electrodes into the plasma column and vice versa.

A quantitative understanding of the corresponding electrode processes should lead to minimizing the ESV in order to improve the luminous efficacy of the discharge lamp. Although there are many attempts to model the cathode processes until recently [1-4], a final decision for a certain model for a given parameter range could not be made up to now [5]. Looking for effects which could be used to discriminate different cathode theories, we chose laser exposure of the electrodes. This additional heating impressively influences the arc voltage and the electrode temperatures, and the effects depend on the exposed electrode (cathode or anode). The results should be used for comparison with different electrode (cathode) models and may contribute to the development of an appropriate anode model.

2. Experiment

2.1. Experimental set-up

A vertically operated high-pressure discharge was studied the electrodes of which were exposed by a diode laser (λ = 808 nm; P_{max} = 37.3 W). The laser was side-on directed on the upper part of the electrode just below the tip. Its beam diameter at the electrode surface was 0.5 mm. The discharge was driven by a current source. The temperatures along the electrodes were determined by a pyrometer IS10 (IMPAC; 0.7 - 1.1 µm) the observation direction of which was at an angle of 90° compared with the laser beam. To diminish the influence of the laser radiation, a notch filter (10^{-4} at the laser wavelength) was used for the pyrometer.

2.2. Discharge configuration and operation mode

The experiments were done in conventional 150-W silica-lamp vessels which are modified by using longer electrodes. Thanks to this measure, the electrode tips are situated in the cylindrical part of the vessel making them accessible for undisturbed optical observations. The electrodes consist of pure tungsten and have a diameter of 0.5 mm. The lamps were filled with 22 mg mercury operating in the unsaturated mode which leads to a working pressure of about 6 bar. This pressure was determined by comparison with similar mercury discharges [6] which were thoroughly investigated earlier. The lamp was vertically operated and driven by a rectangular-wave current (1.9 A, 0.05 Hz). The lower electrode was exposed in a pulsed mode.

2.3. Determination of the absorbed laser power

The percentage η of the laser output power P_L, which is absorbed by the electrode surface, is an essential input for later discussions. In the case of laser heating only (no discharge!), this quantity can be determined by measuring the temperature distribution T(z) along the electrode axis from top (axial coordinate $z = z_1$) to an axial position z_0 ($< z_1$) well apart from the laser-heating region. The absorbed laser power follows immediately from the simplified global energy balance:

$$\frac{4}{\pi d^2}\eta P_L = \left(\lambda\frac{dT}{dz}\right)_{z_0} + \sigma\left(\varepsilon_t T^4\right)_{z_1} + \frac{4\sigma}{d}\int_{z_0}^{z_1}\varepsilon_t T^4 dz \qquad (1)$$

where σ is the Stefan-Boltzmann constant. The thermal conductivity coefficient λ and the total emissivity of the electrode surface ε_t were taken from [7]. It results a laser power input efficiency η = 0.12. This value has been verified by solving the one-dimensional heat conduction equation with constant power input in the electrode tip region. The measured and computed axial temperature distributions agree very well.

3. Results

3.1. Change of arc voltage under exposure

The low frequency of 0.05 Hz corresponds to a quasi-stationary discharge operation. In this operation mode, the laser was always directed at the same electrode (the lower one) which alternatively serves as cathode and anode. The laser power was switched on only for three seconds during each half-cycle starting three seconds after the phase change (see Fig. 1). This operation mode ensures that stationary conditions were reached in the discharge after the change of polarity and further that the temperature increase due to the laser exposure can reach its maximum value.

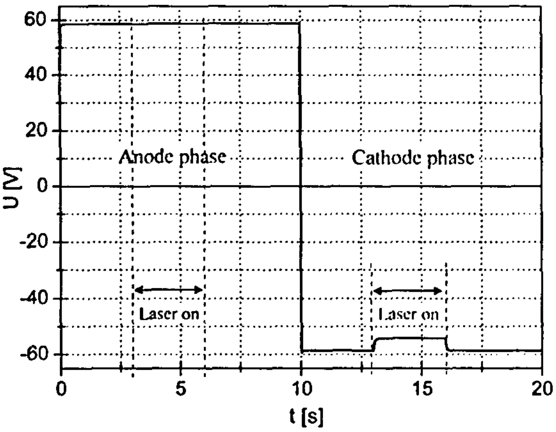

Fig. 1: Arc voltage with laser exposure of the lower electrode during the anode and the cathode phase

At first glance, only during the cathode phase there is a noticeable influence of the laser radiation. The arc voltage is decreased – the maximum laser power of 37.3 W gives rise to a voltage decrease of 4.4 V (Fig. 2). At a higher resolution of the arc voltage in the anode phase, however, there can also be seen a weak influence of the laser (arc voltage changes of about 0.1 V).

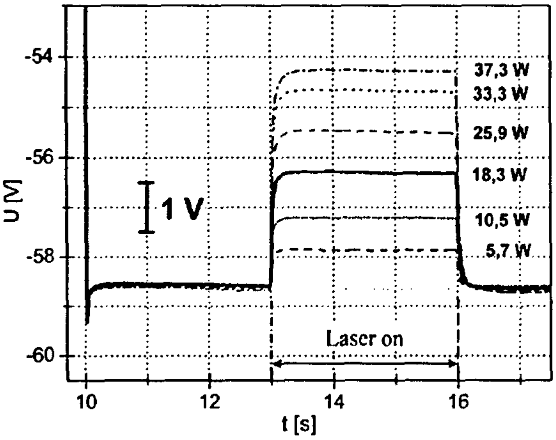

Fig. 2: Arc voltage during pulsed exposure of the cathode

3.2. Change of temperature under exposure

In Fig. 3, the pyrometrically measured temperature of the electrode tip can be seen as a function of time during the operation mode shown in Fig. 1 (rectangular-wave current, laser pulse during the anode and the cathode phase). The most striking feature is the enormous heating of the anode compared with the cathode. Because of the limited calibrated measuring range we can only compare the heating up to a laser power of 18.3 W. In this case, the anode temperature without laser is about 40 K lower than the cathode temperature (2955 K compared with 2995 K). During the laser pulse the anode temperature becomes higher by about 300 K (3255 K) and the cathode temperature only by about 50 K (3045 K); that means a difference in the influence of laser heating of 250 K.

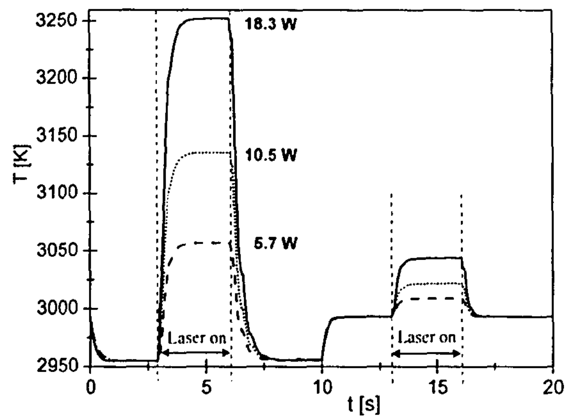

Fig. 3: Temperature at the electrode tip in the anode and cathode phase with laser exposure (cf. Fig. 1)

4. Discussion

The laser radiation hits a target (the tungsten electrode) which is in the cathode phase 40 K hotter than in the anode phase (laser power 18.3 W). This should not make a difference in the percentage of the absorbed laser power, therefore we will assume that in both phases the same amount of laser power is available for the heating of the corresponding electrode. The exposure of the anode causes a temperature increase of the electrode tip of about 300 K, and the change of the arc voltage is negligible. The exposure of the cathode, however, causes a temperature increase of only 50 K, and the arc voltage is simultaneously reduced by about 2.4 V.

This difference leads to the conclusion that in the cathode phase the absorbed laser power is mainly used not for an additional heating of the electrode but for substituting a part of the power which is usually delivered by the cathode fall.

5. References

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